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ASSESSMENT OF THE BILATERAL RELATIONSHIP BETWEEN MUSCLE PENNATION AND FORCE PRODUCTION IN THE QUADRICEPS FEMORIS

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DANIEL JAMES BLACKWOOD
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ASSESSMENT OF THE BILATERAL RELATIONSHIP BETWEEN MUSCLE PENNATION AND FORCE PRODUCTION IN THE QUADRICEPS FEMORIS

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BY

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Dr. Rebecca D. Larson, Chair

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Dr. Christopher D. Black

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Dr. Daniel J. Larson

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ABSTRACT

Few studies have investigated the bilateral symmetry of pennation angle (PA). No research has examined the bilateral relationship between PA and force production (FP). **Purpose:** The purposes of this study were to: 1) determine the magnitude of asymmetry for PA and FP in the quadriceps femoris (QF) muscle group 2) determine if a correlation exists between PA and FP 3) determine if the correlation is symmetrical between limbs. **Methods:** Thirty-eight males age 19-32 were recruited to participate in this study. Twenty-five were resistance trained (RT) and 13 were non-resistance trained (NRT). All subjects performed the same tests during their visits and all measurements were made on both legs. The quadriceps femoris (QF) muscles were measured using B-mode ultrasound. Three screen captures were taken for each muscle: the vastus medialis (VM), vastus lateralis (VL), rectus femoris (RF) and vastus intermedius (VI). QF FP was measured on two separate visits by performing 3 knee extension maximal voluntary isometric contractions (MVICs). Lastly, leg composition was measured by DXA scan for lean mass, fat mass, and bone mineral content (BMC). For statistical analyses individuals' legs were designated strong or weak legs based on FP. **Results:** No significant differences between groups for fat mass, BMC, or PA of any muscle ($p > 0.05$) was seen. The RT group had significantly higher lean mass in the strong (8378.3 ± 1577.2g vs. 7015.5 ± 1120.5g) and weak (8422.0 ± 1526.9g vs. 6898.5 ± 1171.5g) legs and significantly higher FP in the strong (1038.3 ± 235.0N vs. 782.3 ± 242.0N) and weak (950.6 ± 206.0N vs. 711.8 ± 235.4N) legs. The only significant difference found between legs when groups were combined was a higher FP in the strong leg (941.5 ±267.2N vs 878.1 ± 242.1). Only VI was correlated with FP ($p = 0.035$, $r = 0.242$).

CHAPTER I

INTRODUCTION

The quadriceps femoris (QF) muscle group consists of 4 muscles located on the anterior portion of the thigh. This muscle group includes the rectus femoris, vastus lateralis, vastus intermedius, and vastus medialis[1]. The importance of the QF lies in its function as the primary knee extensor[2]. While no athletic movements rely solely on the QF, the majority of force in several key movements is generated by the QF. In dynamic movements such as running, jumping, and decelerating, the QF produces the majority of the propulsive force[3–5]. Even common movements like body weight squats or decelerating during a walk rely primarily on the QF[6,7]. The performance of these muscles during those tasks is largely dependent on the structure of the muscle.

Muscle architecture is typically expressed in terms of muscle fiber pennation angle (PA), fiber length, and cross sectional area (CSA). PA is a measure of the angle at which muscle fibers attach to the deep aponeurosis within a muscle[8]. Fiber length is a measurement of the length of individual fibers within a muscle[9]. Because individual muscle fibers are small and challenging to observe individually the length and angle of whole fascicles, bundles of muscle fibers surrounded by a layer of connective tissue, are frequently measured in place of individual fibers[10]. CSA is a measure of muscle thickness in a plane perpendicular to the muscle. This measurement provides a way of estimating muscle volume. Many researchers will combine their measurements of PA and CSA and express it as physiological cross-sectional area (PCSA). This process gives a more precise depiction of the amount of muscle acting on the muscle tendon[11].

Prior research has shown variations in these factors often lead to differences in performance. A substantial body of evidence has shown that a strong positive correlation exists between muscle CSA and the force production (FP) of that muscle[12–15]. Put simply, a larger muscle can produce more force. Research on varying fiber lengths has shown longer fibers have a higher capacity for contractile speed[16,17]. This higher rate of contractile speed allows for improved performance in skills like jumping and sprinting[16,18]. While a larger PA has been shown to correlate with a higher FP it is usually attributed to an increase in CSA[19]. Additionally, a larger PA also correlates to a decrease in the force per CSA[14]. These factors may be due to the idea that a greater PA allows for an increased amount of muscle but decreases the efficiency at which the entire muscle pulls on the tendon[20].

The complexity of human muscle architecture makes it difficult to maximize the efficiency of the muscle and can result in injuries that seem otherwise unavoidable[21]. As our understanding of the relationship between the components of muscle architecture and strength increases, we may be able to avoid injury and increase performance. The relationship between the strength of the hamstrings and quadriceps has been given substantial consideration for injury occurrence. Imbalances in the strength of these muscle groups have indicated a greater risk for lower body injury[21]. Prior research has also shown bilateral symmetry, or limb-to-limb asymmetry, of PA in the rectus femoris can result in decreased vertical jump power[22]. Bilateral asymmetry of muscle architecture and FP in the quadriceps may be a factor for these strength asymmetries which reduce performance and increase rates of injury. This study attempted to quantify the level of bilateral asymmetry present in resistance trained and sedentary males.

PURPOSE

The purposes of this study were to: 1) determine the magnitude of bilateral asymmetry for PA and FP in the QF 2) determine if a correlation exists between PA and FP 3) determine if the correlation is similar between limbs.

RESEARCH QUESTIONS

1. What is the level of bilateral asymmetry for PA in the QF?
2. What is the level of bilateral asymmetry for knee extension FP?
3. Does a correlation exist between FP and PA in the QF?
4. What is the effect of resistance training on bilateral PA asymmetry?
5. What is the effect of resistance training on bilateral FP asymmetry?
6. What is the effect of resistance training on the level of correlation between PA and FP in the QF?

RESEARCH HYPOTHESES

1. We hypothesized that there would be a correlation between PA and FP in the QF.

2. We hypothesized that the correlation between PA and FP in the QF would be consistent between limbs.

3. We hypothesized that resistance training would alter the correlation between PA and FP in the QF.

NULL HYPOTHESES

1. We hypothesized that there would not be a relationship between PA and FP in the QF.
2. We hypothesized that the correlation between PA and FP in the QF would not be consistent between limbs.
3. We hypothesized that resistance training would not alter the correlation between PA and FP in the QF.

SIGNIFICANCE OF STUDY

Most sports, as well as different positions within each sport, require different levels of power and aerobic fitness. Determining the architecture and FP capabilities of musculature in young athletes could potentially lead to advancements in athletic programming, ensuring of athletic potential is maximized. These advancements could lead to the proper selection of sport and position, helping young athletes in their development.

A disproportionate strength ratio between quadriceps and hamstrings within each individual leg has been shown by Yeung et al. to significantly increase rates of hamstring injury in sprinters[23]. Because disproportionate strength, or asymmetry of strength, within a leg can lead to injury; it is important to look at asymmetrical strength values between legs to determine if the same increased risk is associated with bilateral asymmetry. With further research focused on quantifying the level of architectural asymmetry this measure could potentially be used to identify individuals at higher risk for injury. Additionally, identifying normative values for asymmetry could aid in determining the presence of chronic diseases characterized by bilateral asymmetry, such as multiple sclerosis[24].

DELIMITATIONS

1. Only males age 18-45 were recruited for this study.
2. This study was not applicable to males who participate in resistance training 1 day per week.
3. Participants were only recruited from the Norman area.

LIMITATIONS

1. The sample was recruited only from the Norman area, thus may not be representative of all males age 18-45.
2. Because each individual fiber angle of the quadriceps could not be measured in each subject the estimations may deviate slightly from true quadriceps architecture.

ASSUMPTIONS

1. Individuals in the non-resistance trained group did not have muscle architecture changes in their QF from previous resistance training.
2. Individuals in the resistance trained group had enough prior training to elicit muscle architecture changes.
3. Each individual followed pre-testing guidelines for lower body resistance training.
4. Each individual was able to perform a true MVC during testing visits.
5. Each individual provided an accurate medical and health history.

OPERATIONAL DEFINITIONS

1. Pennation angle (PA) -the angle at which muscle attach to the deep aponeurosis[8].

2. Force production (FP) -the product of mass and acceleration[25].
3. Isometric contraction -a muscle action in which the muscle length does not change because the contractile force is equal to the resistive force[25].
4. Vastus intermedius -knee extensor with highest correlation with knee extension strength[26].
5. Aponeurosis –fibrous extension of tendon to which muscle fascicles attach[20].

CHAPTER II

REVIEW OF LITERATURE

INTRODUCTION

Muscle fibers in many muscles are not parallel to the muscle aponeurosis but are instead angled in a way that allows a greater amount of muscle fiber to exert force on the same length of aponeurosis[27,28]. This arrangement, referred to as the muscle's PA, may be beneficial for increasing the contraction speed and force during the entire range of motion for the whole muscle[27,29]. PA is most accurately measured by using in vivo methods which can allow researchers to observe the discrepancy in angle throughout different locations in the muscle by direct observation[27]. However, it is possible to observe the PA of a muscle without dissection with the aid of ultrasound[10].

An essential muscle group for ambulation as well as performance in most athletics is the QF. Understanding the architecture and function of this muscle group is necessary for understanding and improving performance in any sport or activity which relies heavily on running, jumping, or explosive movements like those seen in Olympic lifting or martial arts. Another reason to further pursue our understanding of muscle architecture and function is examining potential for injury. Asymmetrical strength of the quadriceps and hamstrings can lead to an increased risk of injuries, however, bilateral asymmetry in the quadriceps has not been thoroughly examined[23]. The better we understand the relationship between muscle architecture and muscle performance the better chance we have to identify possible asymmetries that could lead to injury or decreased performance. Understanding how muscle architecture changes in response to training may also improve our attempts to correct muscle imbalances. It is typically not feasible to measure every fiber within every muscle of a muscle group being studied, such as the QF, so it is important to understand the relationships between and within muscles in the group. Fortunately, the QF displays consistent patterns between and within muscles that allow us to make inferences about the architecture of the whole quadriceps group by measuring PA in two muscles, the vastus medialis and vastus intermedius.

MEASURING PA

Chleboun et al. (2001) tested the reliability of using ultrasound to measure muscle PA using an Acuson 128XP real-time ultrasonography scanner (Acuson Sequoia, Acuson Corporation, CA, USA) with a 5MHz 8.0-cm transducer[10]. This study examined the biceps femoris and compared the ultrasound results to an in vivo measurement. Ultrasound measurements were made at knee and hip angles of 0, 40, and 90 degrees for each joint. Three to seven pictures were taken along the long head of the rectus femoris. The in vivo measurements were made by removing entire fibers from cadavers and measuring the angle with a goniometer. The researchers found that measurements from the ultrasound were slightly less accurate than the in vivo measurements but not significantly different ($p > 0.05$, ICC = 0.87). The researchers concluded that bending at the joints did result in significant changes in PA with the highest PA coming at a 90-degree hip angle and a 0-degree knee angle[10]. It is important to note these measures were taken while the muscle was at rest. Additionally, previous studies indicate muscle contraction is another factor, along with joint angle, that will significantly change the muscle architecture[30]. Therefore, to ensure consistency in measurements, subjects should be measured with consistent joint angles and with their limb completely relaxed and supported.

In order to test for correlations between knee extension strength and quadriceps architecture without measuring every muscle's architecture independently, assumptions of a similarity in the mean structure of the quadriceps group have been created[31]. Blazevich et al. (2006) studied the assumption by assessing the relationships among the vastus lateralis (VL), vastus medialis (VM), rectus femoris (RF), and the vastus intermedius (VI) muscles[31]. Sixteen women and fifteen men who did not resistance train had the PA, muscle thickness (MT), and fascicle length (FL) of their quadriceps examined using ultrasound (Acuson Sequoia, Acuson Corporation, CA, USA). Measurements were taken with subjects lying in the supine position and knee bent and supported at a 45˚ angle. Three images of each muscle (VL, VM, RF, and VI) were collected at distal, middle and proximal portions of the muscle with VI being examined in two portions, anterior and lateral. To avoid error from curvature of fascicles as they neared the deep and superficial aponeuroses, the PA of each muscle was measured from approximately 3-4 cm from the deep aponeurosis to the center point of the deep and superficial aponeuroses. MT was determined to be the average of the distance between the aponeuroses at the three measurement sites in each muscle. FL was estimated using PA and MT. Significant correlation was found for within-muscle architecture for the VL for muscle thickness at each site ($r > 0.5$, $P < 0.01$) and for PA between proximal and middle ($r = 0.48$, $P < 0.01$) and proximal and distal ($r = 0.48$, $P < 0.01$) sites. VM displayed a significant correlation for PA between distal and proximal sites ($r = 0.41$, $P < 0.05$) as well as MT at proximal and middle sites ($r = 0.57$, $P < 0.01$). RF displayed a significant correlation for PA between middle and distal sites ($r = 0.38$, $P < 0.05$) and MT for all sites ($0.56 < r < 0.74$, $P = 0.000–0.002$). The anterior portion of the VI displayed a significant PA correlation for the middle and distal sites ($r = 0.47$, $P < 0.05$) and for MT between the proximal and middle ($r = 0.52$, $P < 0.01$) and proximal and distal sites ($r = 0.38$, $P < 0.05$). The lateral portion of the VI displayed a significant correlation for PA between the proximal and distal sites ($r = 0.71$, $P < 0.001$) and no significant correlations for MT. A difference index was calculated to compare overall muscle structure, or architectural similarity, and revealed a low difference index for the VL, VM, and RF muscles but not for either portion of the VI. Trends between muscles were calculated using z-scores to provide a parameter for the entire quadriceps group. It was determined higher angles in the VM were indicative of higher angles in the VL and RF. A mirrored trend was also seen for individuals with a larger RF PA having a larger PA in their VL and VM. These trends were not seen in the VI when compared to other muscles. MT of one muscle was not an accurate determinant of MT in other muscles except between VL and the anterior portion of the VI. Using regression equations to determine each variables indication of whole muscle architecture it was found the MT of the VM and the PA of the VM were the two best predictors of whole muscle architecture. When looking at the interaction of muscle parameters the VL, VM, and portions of the VI showed significant correlations between MT and PA, but not for RF. The results of this study show the superficial quadriceps muscles have a similar architecture. This trend allows us to use the structure of one superficial muscle to assume, with relatively high confidence, the structure of the other superficial muscles. The results do show the VI to be only vaguely related to the superficial muscle, but not enough to make assumptions about the structure of the quadriceps as a whole. Because PA is a strong indicator of MT, and because the VM is a strong predictor of the whole muscle architecture, we can assume that measuring the PA of the VM and the VI will give us a strong idea of the whole quadriceps muscle group[31]. This assumption is necessary in order to investigate correlations between muscle architecture of the quadriceps and performance of the muscle group as a whole when it is not feasible to measure the MT and PA of each muscle individually. The data also provided a reference for which areas on each muscle (proximal, middle, or distal) are most closely related to the architecture in the other areas. These data provide us confidence to assume the architecture of the entire quadriceps group from measuring PA of the proximal anterior VI and PA of the proximal VM.

PA AND EXERCISE

PA can change after training and previous observations have allowed us to understand how PA will likely change in response to some modes of exercise. A study by Farup et al. (2012) looked at the muscle morphological changes seen from 10 weeks of resistance training (RT) and 10 weeks of endurance training (END) [32]. The resistance training program consisted of 3 training sessions each week. During the sessions subjects would perform 3-5 sets of 4-10 repetitions of leg press, hamstring curl, and knee extensions with the load adjusted to a percentage of their 1RM. The first 15 sessions utilized 2 minutes of rest between sets. Rest time increased to 3 minutes between sets for the last 15 training sessions. The endurance training was structured based on subjects' VO2max test performance. Subjects warmed up on a stationary bicycle (Kettler Ergoracer GT, Kettler, Enseparsit, Germany) then performed various exercises. The exercise for the first weekly session was 30-45 minutes of cycling at 60-75% of the athlete's watt max. The second weekly session split the cycling into two 20 minute bouts at 70-80% of the athlete's watt max with 5 minutes of light cycling between bouts. The third weekly sessions was split into 8 bouts of 4 minutes at 80-90% of the athlete's watt max with 1 minute of light cycling between bouts. The findings of the study showed that RT resulted in an increase in muscle CSA of 19 ± 7% as well as a PA increase from 10.4 ± 0.9˚ to 12.9 ± 1.4˚. However, END did not evoke any significant changes in fiber CSA or PA. The authors speculated that the alterations in PA seen following the resistance training protocol were due in part to the increased muscle fiber CSA causing an increase in muscle fiber stiffness as seen in previous literature[33]. The authors also speculated that the lack of alterations in PA following the endurance training protocol may be due to the fact that muscle CSA did not change after the 10 weeks of training. This is in accordance with more recent literature examining the effect of endurance training on muscle architecture in the rectus femoris[34]. These results also supported their claim that the CSA change in the RT group is what led to the changes in muscle PA. Based on the findings of the current study it appears that resistance training is the primary exercise modality to improve PA[32].

A study by Stock et al. (2016) examined how different volumes of resistance training could affect muscle architecture[35]. This study utilized a control group who performed no resistance training, a low volume resistance group who performed two sets of 5 repetitions per exercise during each session, and a moderate volume resistance group who performed four sets of 5 repetitions per exercise during each session. The two experimental groups performed resistance training, consisting of both deadlifts and back squats, twice a week for four weeks. Extensive training was completed for each exercise before training began. The greatest effect size seen from pretest to posttest (d = 0.67) was seen in the moderate volume group's PA of the vastus lateralis. The vastus lateralis PA in the moderate volume group showed a pretest to posttest effect size (d = 0.57). The pretest to posttest effect size for vastus lateralis muscle thickness was greater in the moderate volume group (0.48) than in the low volume group (0.26)[35]. The results of this study conflict with previous research that suggested PA may increase following resistance training due to an increase in muscle CSA[32].

This discrepancy between CSA and PA change was also seen in a study by Baroni et al. (2013), whose study examined muscle PA, CSA, and fascicle length before and after a training program[36]. The training protocol consisted of 20 subjects who performed 12 weeks of isokinetic eccentric knee extensions. Despite a CSA change of around 7-10%, there were no significant changes in PA. The researchers concluded that the change in CSA must have been solely due to a 17-19% change observed in muscle fascicle length[36]. In light of this study and the study by Stock et al. (2016) we must realize PA will often change with CSA, but not always to the same degree. From the data we can also assume it is possible to change CSA and PA somewhat independently of each other, specifically CSA through the implementation of eccentric resistance exercise. However, changes in fascicle length may not be common for athletes participating in typical resistance training programs as shown by Fukutani et al. (2015) who compared muscle architecture of the vastus lateralis and medial gastrocnemius in a group of 16 bodybuilders and rugby player to 11 individuals who did not regularly participate in resistance training[37]. The results showed PA and muscle thickness were higher in the trained individuals but fascicle length was similar. This data from these studies indicate fascicle length may be somewhat stable unless a program is structured around consistent eccentric loading[37].

PA AND PERFORMANCE

The importance of measuring muscle PA was detailed by Ichinose et al. (1998) in a study examining the relationship between PA and force generation capability[19]. The relationships between muscle CSA and PA and between CSA and force generation capability were also measured. Athletes from sports requiring high force, like judo, wrestling, and gymnasts, consistently showed greater PAs on average (23.6˚) compared to other sports like sprinting, soccer, rowing, and baseball (17.8˚). The study also found that muscle PA significantly correlated with muscle CSA ($r = 0.580$, $p < 0.05$). However, the results of this study also showed that force per CSA exhibits a negative correlation, with smaller muscles being comparatively stronger than larger muscles. These findings suggest that PA may be a determining factor in an athlete's success in a specific sport[19]. It may be beneficial to screen young athletes to determine their PA and muscle architecture, and use those findings to guide them towards sports where individual success is maybe likely.

A study done by Secomb et al. (2015) detailed how PA and muscle CSA of the lower limbs correlate with squat jump performance[15]. PA and CSA of the vastus lateralis and gastrocnemius both showed a significant correlation ($p < 0.01$) with performance of a squat jump, countermovement jump, and isometric mid-thigh pull with correlation ranging from moderate ($r = 0.45$) to very large ($r = 0.73$). These findings give us straightforward data that athletes with greater PAs may have greater success with jumping skills like high jump or long jump as well as sports like basketball and volleyball that incorporate a large volume of jumping[15].

Another consideration for PA measurements is how it correlates with FP and FP per CSA (F/CSA). Ikegawa et al. (2008) examined the FP, CSA, and PA of the long head of the triceps brachii in 32 competitive male bodybuilders and 20 collegiately ranked Olympic weightlifters[14]. FP was collected by conducting a maximal isometric contraction with an isokinetic dynamometer (DTM, SAKAI medical electronics, Tokyo) and CSA was collected using an ultrasonic apparatus CSA (ALOKA SSD-120 with a circular compound scanner) specifically designed for measuring muscle without direct contact using a frequency of 5MHz. PA was measured at the triceps brachii using a B-mode ultrasonic apparatus (ALOKA SSD-500). The results showed the bodybuilders had a greater average CSA, mean isometric muscle force, and average PA (36.8 ± 10.3 cm^2, 4499 ± 1157 N, 34.4 ± 11.7°) than the weightlifters (23.6 ± 5.9 cm^2, 3553 ± 725 N, 21.7 ± 6.22°). However, F/CSA was significantly larger in the weightlifters (153.5 ± 22.4 N/cm^2) than in the bodybuilders (127.7 ± 34.0 (N/cm^2). In both groups there was a close relationship between PA and CSA while F/CSA was negatively correlated with PA, leading the authors to suggest that "the larger PA is associated with lower force generating capacity in strength trained athletes[14]." This research along with the research of Stock et al. (2016) and Ichinose et al. (1998) can be viewed collectively to examine the importance of different body types as well as different types of training for athletes who wish to excel in various sports[19,35].

ASYMMETRY/SUMMARY

To gain an understanding of the relationship between muscle function and muscle architecture the first step is ensuring accurate measurements of both. Ultrasound measurements of the vastus medialis and vastus intermedius can provide an accurate depiction of the QF group without measuring each individual muscle[10,31]. However, when using ultrasound we must ensure consistent limb angles within and between subjects in addition to supporting the limb to avoid muscular contraction[10,30]. Previous research suggest larger PAs are associated with a greater FP and explosive movements like jumping[15,19]. This data corresponds with research showing an increase in PA following resistance training[32,35,37]. While extensive research has examined the relationship between muscle architecture and FP within a single leg no research has examined the bilateral symmetry of that relationship. It appears as though the only study examining asymmetry of PA in the quadriceps group was performed by Mangine et al (2014). However, this study only looked at bilateral asymmetry of the rectus femoris and vastus muscles and the effect of that asymmetry on vertical jump and sprint performance. The researchers did suggest PA asymmetry in women correlated with a decrease in jumping and sprinting performance, however, the magnitude of this decrease was not addressed[22]. Asymmetrical strength of muscle groups within a leg has also been associated with an increased risk for injury as shown by Yeung et al. (2009), who studied the relationship between hamstring and quadriceps strength[23]. Considering the findings of Mangine et al. (2014) and Yeung et al. (2009) it may be beneficial to isolate the force produced from the muscles being examined in order to gain a more accurate depiction of the bilateral asymmetry of architecture, strength, and the relationship between architecture and strength[22,23]. Identifying normal levels of bilateral asymmetry may be beneficial for maximizing lower limb efficiency, injury prevention, or recovery from injury. If the relationship between quadriceps architecture and strength appears to be consistent within healthy individuals it could also be used to identify a decreased ability to activate the entire muscle group.

CHAPTER III

METHODOLOGY

This chapter will cover the methods used for this study. This includes participant description, participant inclusion and exclusion criteria, descriptions of the data collection protocols, instrumentation, and statistical analyses used.

SAMPLE

Thirty-eight males between the ages of 18 and 45 were recruited to participate in this study. Twenty-five were lower body resistance trained (RT) and 13 were non-resistance trained (NRT). To qualify as RT the subject must have participated in lower body resistance training two or more times a week for at least 3 months prior to testing to allow sufficient time for morphological changes[38]. To qualify as NRT the subject must not have regularly participated in lower body resistance training during the 12 months prior to testing. Participants were excluded if they had begun a resistance training program during the past 3 months. All subjects signed an informed consent document approved by the University of Oklahoma Institutional Review Board (Norman Campus). Individuals residing in the Norman area were recruited by flyers, word of mouth, and e-mail to participate.

INCLUSION CRITERIA

All participants were required to meet these criteria to be eligible for participation:

1. Be in the age range of 18-35 years old

2. Have participated in lower body resistance training at least twice a week during the past 3 months or have not participated in regular lower body resistance training during the past year.

EXCLUSION CRITERIA

Reasons that excluded subjects from participating in the study were as follows:

1. Individual had a prior injury which limits knee range of motion.
2. Individual was unable to perform a knee extension maximal voluntary contraction.
3. Individual had undergone surgery that may have altered architecture of the quadriceps.
4. Individual had cardiovascular diseases.
5. Individual had neurological diseases.
6. Individual had neurological damage.
7. Individuals who started lower body resistance training 3 or fewer months before the start of the study.
8. Individual who had metal implants in the lower limbs that would impact body composition assessments.

RESEARCH DESIGN

This study utilized a cross sectional design which consisted of 3 visits with at least 24 hours between visits. We requested the participants avoid any lower body resistance training or endurance training 24 hours prior to testing. Testing protocols during each visit were the same for both groups. The first visit began with an explanation of inclusion and exclusion criteria and a brief explanation of the protocols included in the study. Subjects then read and signed an informed consent form followed by filling out a physical activity readiness questionnaire (PAR-Q) and a Health Insurance Portability and Accountability Act (HIPPA) form. Once consent was given subjects completed an International Physical Activity Questionnaire (IPAQ). We then recorded age and gender before measuring height, weight, resting blood pressure (BP), and heart rate (HR). Next, we measured the PA of the VM, VL, RF, and the anterior VI of both legs starting with the right leg. This was followed by a familiarization protocol for knee extension isometric MVC using an isokinetic dynamometer. Subjects went through the familiarization for both of their legs. The order of leg familiarization was randomized for visit 1 and alternated for visits 2 and 3. During the second visit we started by measuring weight, resting BP, resting HR, and hydration status. We then tested the knee extension isometric MVC of both legs. Visit three once again began with measurements of weight, resting BP, resting HR, and hydration status. We then measured body composition and repeated the knee extension isometric MVC testing protocol.

PROCEDURES

INITIAL MEASURES

Height without shoes on was measured in centimeters to the nearest 0.5cm with the use of a stadiometer (Seca Model 242, Chino, CA). Subjects stood with their back to the wall, looking straight forward, and took a deep breath just prior to measurement. Weight without shoes or excessive clothing was measured in kilograms to the nearest 0.1kg with an electronic scale (Tanita Model BWB-800, Tokyo, Japan). During visit 3 hydration status was determined by measuring urine specific gravity with a refractometer (CLX-1, VEE GEE Scientific Inc., Kirkland, WA). BP and HR were taken following 5 minutes of rest using an automatic BP monitor (BP742 HEM-7200-Z, OMRON Healthcare Inc., Lake Forest, IL).

PENNATION MEASUREMENT

PA was collected using an ultrasound apparatus (LOGIQ S8, GE Healthcare, Little Chalfont, United Kingdom). Subjects were seated with both hips and knees at a 90˚ angle. Subjects' backs, knees, and feet were adjusted and supported to ensure those angles could be maintained with the entire lower body completely relaxed. We measured PA of the muscles for all subjects in this order: right leg VM, right leg VL, right leg RF, right leg VIA, left leg VM, left leg VL, left leg RF, and lastly left leg VIA. All measurements were made with the probe angled perpendicular to the leg and parallel to the muscle such that an imaginary line extending out from the probe would go straight through the muscle roughly in the sagittal plane of the body. Prior to measurements a water-soluble gel was applied to the probe to maximize acoustic perfusion into the muscle, thus minimizing the amount of pressure applied to obtain a clear image of muscle fascicles. We began the measurement process by locating the anterior superior iliac spine and the superior border of the patella. This distance between these two was considered the subject's thigh length (TL) and measurement locations were oriented based on a straight line (ML) between the two. To locate the proximal end of the VIA we used a marker to indicate the area lying 27% of TL distal from the anterior superior iliac spine along the ML. To locate the proximal end of the VM we used a marker to indicate the area lying 61% of TL distal from the anterior superior iliac spine along the ML. RF was measured in the same location as VIA and VL was measured laterally from VIA location where the leg was perpendicular to the ground. Any proximal, distal, medial, or medially or laterally deviation from these points required to find an accurate PA measurement was measured and used to locate the same position on the left leg. Three screenshots were taken for each muscle with slight lateral or medial deviations made in probe position to ensure a more complete picture of the muscle was captured. All pictures were analyzed using an on-screen protractor (MB-Ruler 5.3, MB-Softwaresolutions, Iffezheim, Germany). This was done by aligning the base line of the protractor with the aponeurosis of the muscle, then moving the origin to one end of an identifiable fascicle, and recording the angle at which that fascicle intercepted the baseline. This was done for three fascicles in each picture. The averages for all 3 pictures of each muscle were combined and this was the recorded PA. All subjects were measured by the primary researcher and compared against blind measurements of 24 subjects completed by a secondary researcher.

DYNAMOMETER TESTING

Familiarization for knee extension isometric MVC consisted of having the subject sit upright on the KinCom dynamometer (KinCom model: KC125AP, Isokinetic International, East Ridge, TN 37412) and adjusting the seat until knee and hip angles were both 90˚. The KinCom was adjusted so the rotational axis of the dynamometer head was aligned with the subject’s knee. Seat and dynamometer head position was recorded for subsequent visits. Straps were then fastened to secure the upper body to the seat to ensure leg extensors were isolated. The subject’s ankle was then strapped to the load cell of the KinCom. Subjects were asked to perform isometric knee extensions at perceived efforts of 25%, 50%, and 75% followed by one maximal effort attempt to ensure they feel comfortable with the protocol. This process was then repeated for the opposite leg.

DXA SCAN

Body composition was measured using a whole-body Lunar dual-energy x-ray absorptiometry (DXA) scanner (with software version 13.60.033, GE-Lunar Prodigy Advanced, Madison, WI). The DXA scanner was calibrated each day prior to data collection. Subjects removed their shoes, jewelry, and any clothing or personal items that may have contain metal prior to starting the scan. Subjects then were positioned in the supine position with the middle of the table aligned with the middle (sagittal plane) of their body. Subjects were asked to place their arms at their sides within the measurement zone, hands pronated perpendicular to the table, leaving space between their arms and their sides. Straps were used to secure the subject's feet to limit movement during the scan. Following the scan, regions of interest were placed around the thigh using the proximal border of the patella and the anterior superior iliac spine as landmarks to examine composition of each leg individually. If the subject could not fit in the measurement zone a split scan was utilized. This involved moving the subject until either their left or right side were completely in the scanning zone, running the scan, then moving them until the other side of their body was completely in the scanning zone then running a second scan.

STATISTICAL ANALYSES

All results are reported as means ± standard deviation (SD). Subjects' legs were designated as their strong or weak leg by averaging the two highest MVIC values from the second visit with the two highest values from the third visit. Two-way repeated measures ANOVAs were used to determine differences between groups' strong and weak legs for composition (fat, lean and bone), PA, and FP. When significant interactions and effects were found, Bonferroni corrections were used to determine where specific between and within-group differences were located. Paired t-tests look at between leg differences after collapsing groups. Two Pearson's r Correlations were used: one examined group and bilateral relationships between PA and FP and the second examined the relationship of PA of all legs combined with FP. Statistical significance was set at $p \leq 0.05$. Cohen's d effect sizes were analyzed when appropriate. A value of < 0.19 was considered trivial, 0.20-0.49 was considered a weak effect, a value of 0.50-0.79 was considered a moderate effect, and a value of $\geq$ 0.80 was considered a strong effect[39]. All statistical analyses were done using Sigmaplot for windows (Version 12.5, Systat Software Inc., Chicago, IL).

CHAPTER IV

RESULTS AND DISCUSSION

The first goal of this project was to determine if bilateral asymmetry is present for PA, FP, and the relationship between PA and FP in the muscles of the QF. The second goal was to determine if resistance trained individuals displayed similar patterns of asymmetry, if present, for these variables. This chapter will discuss the following: subject characteristics, group differences, and the bilateral relationship between PA and FP.

RESULTS

SUBJECT CHARACTERISTICS

Twenty five RT and 13 NRT males participated in this study. All subjects consented completed the entirety of the study. All RT individuals had been participating in consistent resistance training for at least 12 weeks prior to their first visit. All NRT individuals had not consistently resistance trained during the past year and were asked to refrain from beginning a training program while participating. All RT subjects refrained from lower body resistance exercise for at least 24 hours prior to testing. A paired t-test revealed a significant difference between groups for age ($p = 0.04$) and body fat percentage ($p = 0.001$) but not for height, weight, or BMI ($p = 0.489, 0.152, 0.0676$). Group characteristics are displayed in Table 1.

Table 1. Subject Characteristics (Mean (SD))

Groups			
Variables	**Trained (n = 25)**	**Untrained (n = 13)**	**Cohen’s d**
Age (years)	22.2 (2.2)	23.8 (3.0)*	0.61
Height (cm)	180.2 (6.8)	180.2 (7.1)	0.00
Weight (kg)	89.9 (14.8)	86.2 (14.6)	0.25
BMI	27.6 (3.5)	26.5 (3.8)	0.30
Body Fat %	19.9 (7.4)	27.5 (5.4)*	1.17

Differences if present were denoted using *(p<0.05). Standard deviations represent variability.

GROUP DIFFERENCES

A two-way repeated measures ANOVA determined no significant group x leg effect for %fat ($p = 0.895$), fat mass ($p = 0.157$), or bone mineral content (BMC) ($p = 0.496$). However, there was a significant group x leg interaction for lean mass ($p = 0.037$). An 18% difference was seen between the strong legs of the RT (8378.3 ± 1577.2g) and NRT (7015.5 ± 1120.5g) groups as well as a 20% between the weak legs of the RT (8422.0 ± 1526.9g) and NRT groups. Tables 2A and 2B display the difference in means (strong - weak, RT - NRT) for all leg composition measures. A second two-way repeated measures ANOVA determined no significant group x leg effect for PA [VM ($p = 0.470$), VL ($p = 0.795$), RF ($p = 0.431$), VI ($p = 0.563$)]. A significant group x leg effect was present for FP ($p = 0.003$). A Bonferroni post-hoc analysis revealed a significant difference in means between groups ($p = 0.003$) and a significant difference in means between legs of ($p = < 0.001$). Results are listed in Tables 3A and 3B. Because no significant group differences were present for muscle architecture or in the strong - weak difference for FP, the groups were collapsed and further analyses compared the strong and weak legs of both groups combined.

Table 2A. Group Differences in Leg Composition

	Groups							
Variable	**Strong (n =38)**				**Weak (n = 38)**			
	RT	NRT	%diff	Cohen's d	RT	NRT	%diff	Cohen's d
Lean mass (g)	8378.3 (1577.2)	7015.5 (1120.5)*	18%	1.00	8422.0 (1526.9)	6898.5 (1171.5)*	18%	1.12
Fat mass (g)	2644.7 (1194.7)	3345.3 (1043.6)	-23%	0.62	2684.8 (1219.7)	3310.9 (987.1)	-22%	0.56
BMC (g)	333.3 (70.7)	316.5 (78.0)	5%	0.23	335.0 (65.8)	313.4 (76.3)	6%	0.30

Differences if present were denoted using *($p<0.05$). Standard deviations represent variability. RT: Resistance trained group; NRT: Non-resistance trained group; %diff: Strong - weak

Table 2B. Leg Differences in Leg Composition

	Groups							
Variable	**RT (n =25)**				**NRT (n = 13)**			
	Strong	Weak	%diff	Cohen's d	Strong	Weak	%diff	Cohen's d
Lean mass (g)	8378.3 (1577.2)	8422.0 (1526.9)	18%	0.03	7015.5 (1120.5)	6898.5 (1171.5)	18%	0.10
Fat mass (g)	2644.7 (1194.7)	2684.8 (1219.7)	-23%	0.03	3345.3 (1043.6)	3310.9 (987.1)	-22%	0.03
BMC (g)	333.3 (70.7)	335.0 (65.8)	5%	0.02	316.5 (78.0	313.4 (76.3)	6%	0.04

Differences if present were denoted using *(p<0.05). Standard deviations represent variability. RT: Resistance trained group; NRT: Non-resistance trained group; %diff: Strong - weak

Table 3A. Group Differences in PA and FP

	Groups							
Variable	**Strong (n =38)**				**Weak (n = 38)**			
	RT	NRT	%diff	Cohen's d	RT	NRT	%diff	Cohen's d
VM°	11.6 (3.0)	11.6 (3.8)	0%	0.00	11.6 (3.3)	12.2 (3.8)	-5%	1.12
VL°	12.1 (2.0)	11.2 (2.6)	8%	0.39	11.5 (2.6)	11.3 (2.3)	2%	0.17
RF°	12.0 (1.9)	13.0 (2.1)	-8%	0.50	12.6 (2.0)	11.8 (2.0)	7%	0.40
VI°	9.9 (1.7)	9.8 (4.2)	0%	0.03	10.3 (3.0)	8.8 (3.0)	16%	0.50
FP (N)	1038.3 (235.0)	782.3 (242.0)*	28%	1.07	950.6 (206.0)	711.8 (235.4)*	29%	1.08

Differences if present were denoted using *($p<0.05$). Standard deviations represent variability. RT: Resistance trained group; NRT: Non-resistance trained group; %diff: Strong - weak

Table 3B. Leg Differences in PA and FP

	Groups							
Variable	**RT (n =25)**				**NRT (n = 13)**			
	Strong	Weak	%diff	Cohen's d	Strong	Weak	%diff	Cohen's d
VM°	11.6 (3.0)	11.6 (3.3)	0%	0.00	11.6 (3.8)	12.2 (3.8)	-5%	0.16
VL°	12.1 (2.0)	11.5 (2.6)	5%	0.26	11.5 (2.6)	11.3 (2.3)	2%	0.08
RF°	12.0 (1.9)	12.6 (2.0)	-5%	0.31	13.0 (2.1)	11.8 (2.0)	10%	0.59
VI°	9.9 (1.7)	10.3 (3.0)	4%	0.16	9.8 (4.2)	8.8 (3.0)	11%	0.27
FP (N)	1038.3 (235.0)	950.6 (206.0)*	9%	0.40	782.3 (242.0)	711.8 (235.4)*	9%	0.30

Differences if present were denoted using *($p<0.05$). Standard deviations represent variability. RT: Resistance trained group; NRT: Non-resistance trained group; %diff: Strong - weak

COMBINED DIFFERENCES

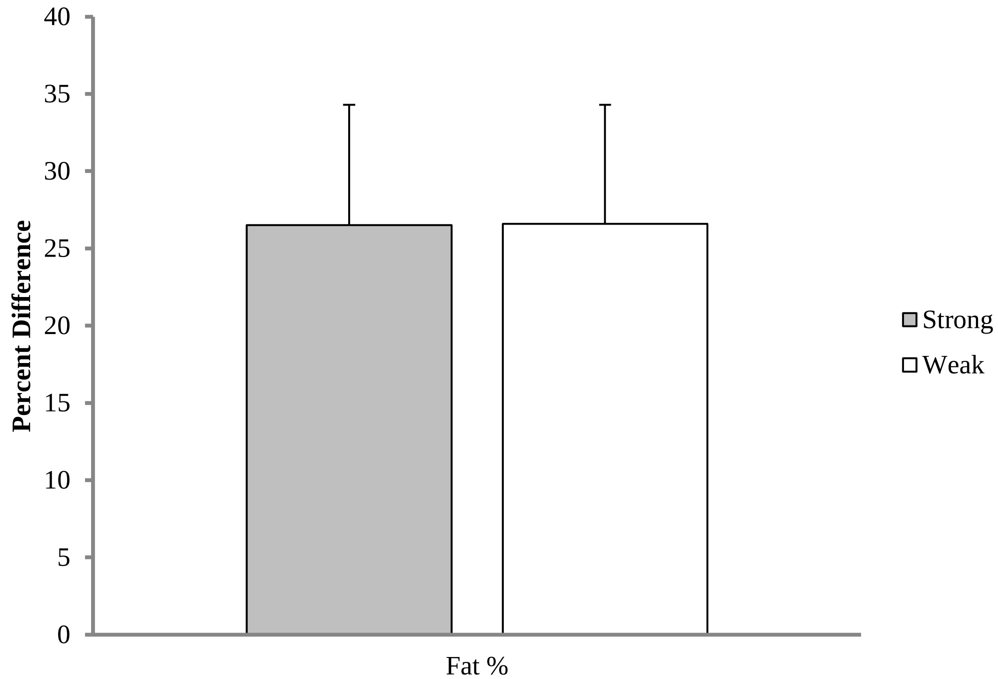
After collapsing the groups paired t-tests were used to assess between leg differences. Table 4 contains a breakdown of the strong and weak legs for fat%, lean mass, fat mass, and BMC. No significant differences were observed between the legs. The data displayed in figures 1A-1C illustrate the difference between the legs.

Table 4. Leg Compositional Differences (Mean (SD))

	Legs			
Variables	**Strong (n = 38)**	**Weak (n = 38)**	**% Difference**	**Cohen's d**
Fat %	26.5 (7.8)	26.6 (7.7)	-0.4%	0.01
Lean mass (g)	7912.1 (1565.3)	7900.8 (1579.2)	0.1%	0.01
Fat mass (g)	2884.4 (1180.1)	2899.0 (1171.2)	-0.5%	0.01
BMC (g)	327.5 (72.6)	327.6 (69.3)	0.0%	0.00

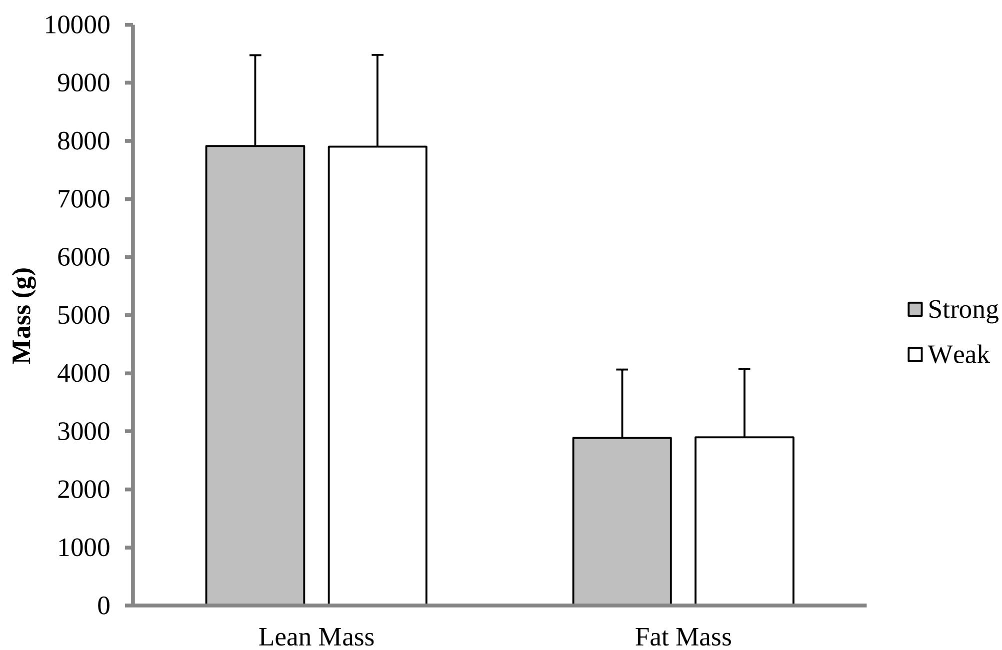
Differences if present were denoted using *(p<0.05). Standard deviations represent variability.

Figure 1A. Leg Fat Percentage Differences



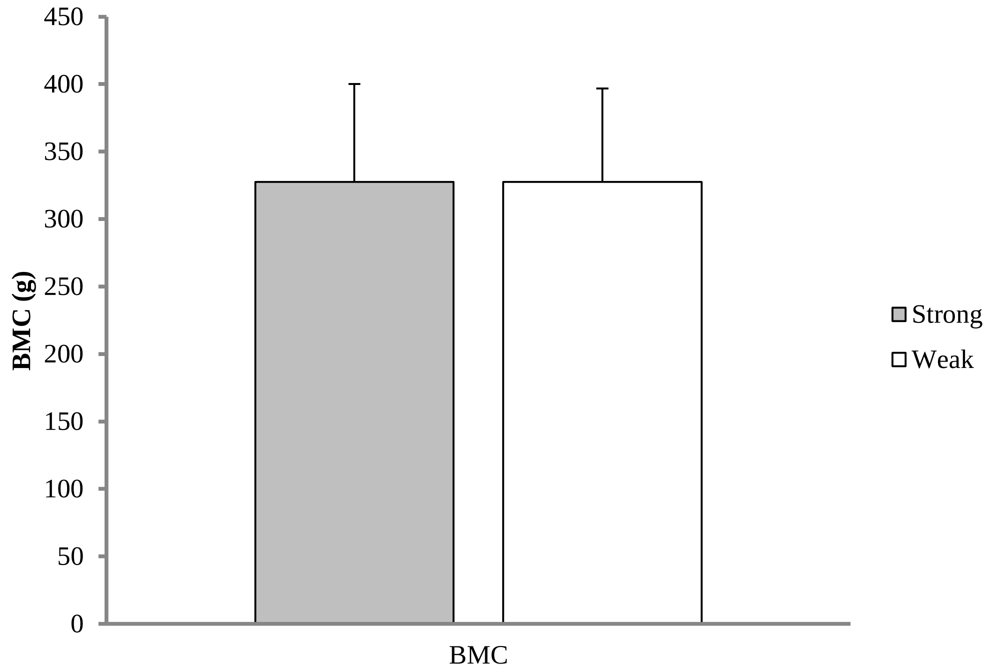
Differences if present were denoted using *(p<0.05). Standard deviations represent variability.

Figure 1B. Leg Lean and Fat Mass Differences



Differences if present were denoted using *(p<0.05). Standard deviations represent variability.

Figure 1C. Leg Bone Mineral Content Differences



Differences if present were denoted using *(p<0.05). Standard deviations represent variability.

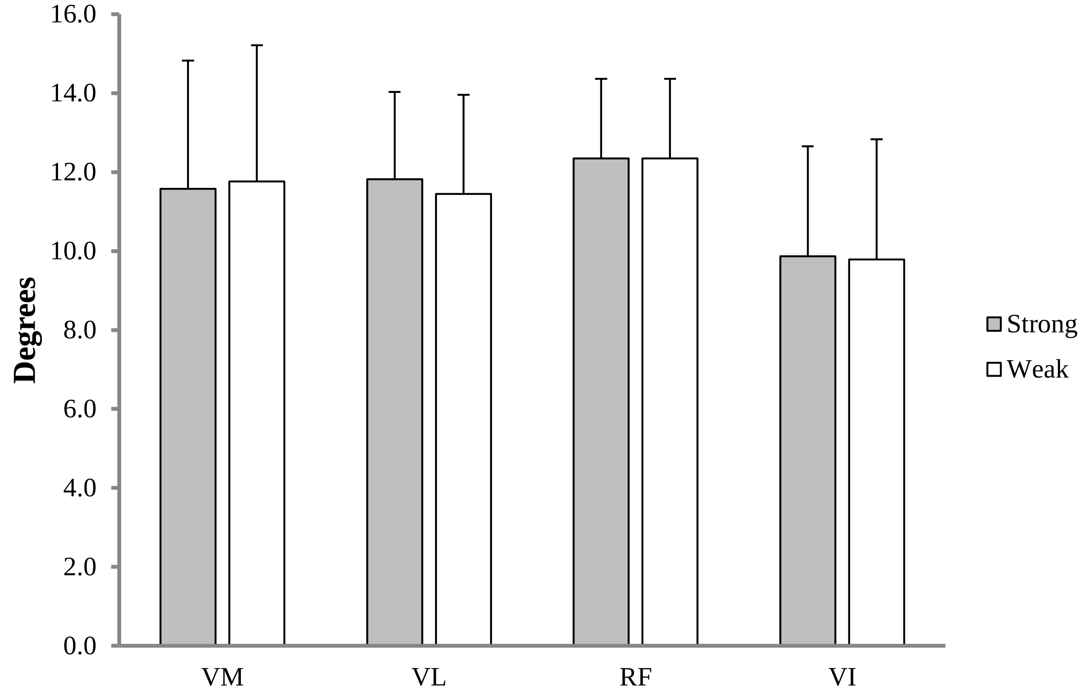
Paired t-tests were used to determine if any significant differences were present between the strong and weak leg for FP and PA. Differences are shown in Figures 2A and 2B. Only FP was significantly different ($p < 0.001$). Magnitudes of difference are shown in Table 5.

Table 5. Leg PA and FP Comparison [Mean (SD)]

	Legs			
Variables	**Strong (n = 38)**	**Weak (n = 38)**	**% Difference**	**Cohen's d**
VM (°)	11.6 (3.2)	11.8 (3.5)	-1.7%	0.06
VL (°)	11.8 (2.2)	11.4 (2.5)	3.4%	0.17
RF (°)	12.3 (2.0)	12.3 (2.0)	0.0%	0.00
VI (°)	9.9 (2.8)	9.8 (3.0)	1.0%	0.03
Force (N)	941.5 (267.2)	878.1 (242.1)*	7.0%	0.25

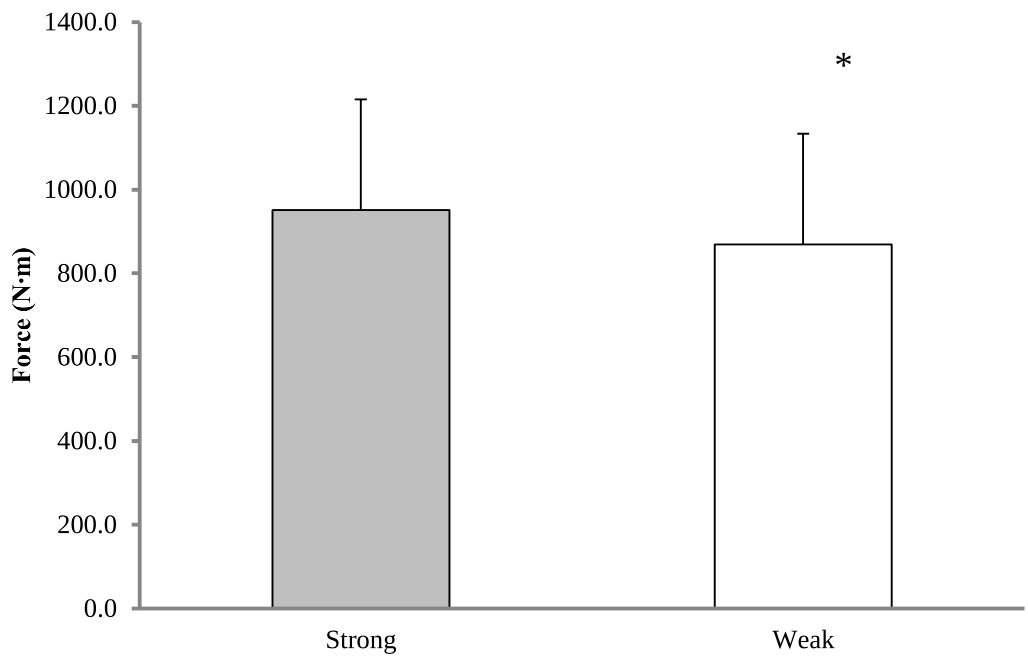
Differences if present were denoted using *($p<0.05$). Standard deviations represent variability.

Figure 2A. Leg Muscle Pennation Differences



Differences if present were denoted using *(p<0.05). Standard deviations represent variability.

Figure 2B. Isometric Knee Extension Force Differences



Differences if present were denoted using *(p<0.05). Standard deviations represent variability.

Pearson's r correlations were used to determine if a correlation was present between the PA of each individual muscle and FP. This test revealed FP was only significantly correlated with VI ($p = 0.035$, $r = 0.242$). Pearson correlation results are shown in Table 6.

Table 6. Correlation of Muscle PA with FP (n = 76)

Variables	r	p
VM	-0.022	0.053
VL	0.072	0.538
RF	0.053	0.647
VI	0.242	0.035*

Differences if present were denoted using *($p<0.05$). Standard deviations represent variability.

DISCUSSION

This section will present a detailed account of the results found in this study for both groups separated and combined. Results will be examined with respect to previous literature.

MAIN FINDINGS

1. **The difference in PA between the strong and weak limbs, as determined by knee extension MVIC, is not significantly different between resistance trained and non-resistance trained males.**

2. **Lean mass and FP are significantly greater in the strong and weak limbs of resistance trained males compared to non-resistance trained males.**
3. **The PA of the individuals muscles of the QF; the VM, VL, RF, and VI; are not significantly different between the limbs.**
4. **FP of a knee extension MVIC is significantly greater in the strong leg.**

ASYMMETRY IN GROUPS

The results of this study showed PA in the QF muscles was not significantly different between the strong and weak legs in males, regardless of resistance training status. To our knowledge, the only prior studies which measured bilateral PA asymmetry were conducted by Secomb et al. (2015) and Mangine et al. (2014), each of which reported similar findings[15,22]. The study by Secomb et al. examined the PA differences in the VL and lateral gastrocnemius. Reported differences were between the left and right legs, not between dominant and non-dominant based on strength, architecture, or preference. No significant difference ($p > 0.05$) was seen as the mean differences in PA were only 0.7% and 1.2% for the VL and lateral gastrocnemius respectively[15]. Mangine et al. measured the differences in PA of the RF and VL between the legs as well as between men and women. The leg with the larger CSA in the VL was designated the dominant leg. Mean differences of 3.9% and 4.8% in men and 4.3% and 4.8% in women were seen in the RF and VL respectively. Although larger than the 0.8% and 3.4% differences seen in those muscles in the current study, the differences in their study also failed to reach statistical significance ($p > 0.05$)[22]. In addition our study did not separate the limbs based on CSA but rather strength. Their study also examined the bilateral differences in muscle thickness, fascicle length, and CSA between the limbs. No measures reached statistical difference except for a 2.0% difference in CSA of the VL in men ($p = 0.028$)[22]. These results are further supported by a previous study by Masuda et al. (2003) which found no significant difference ($p > 0.05$) in the CSA of the QF between the kicking legs and non-kicking legs of university level soccer players[13]. Although the current study did not measure MT or CSA independently, the results of the DXA scan revealed similar findings as no significant differences in lean mass, fat mass, or BMC between the legs was found. Absolute differences in lean mass were only 0.1% between the strong (7912.1 ± 1563.5g) and weak (7900.8 ± 1579.2g) legs ($d = 0.01$). These previous studies paired with the results of the current study suggest muscle size and PA tend to be symmetrical between the legs in healthy young individuals.

Although symmetry was found between the legs for muscle PA, a significant difference of 7.0% in FP was present between the legs ($p < 0.001$). These results are similar to the results of the previously mentioned study by Masuda et al. (2003) which reported a significant difference ($p < 0.05$) between the limbs for isokinetic knee extensions performed at 240°/second. The 4.3% difference between legs was slightly less than the 7.0% difference seen between legs in the current study[13]. Greater differences of 10% and 5% were seen in a different study by Brown et al. (2016) which examined peak force of knee extensions 60°/sec in forwards, traditionally larger and stronger players, and backs, traditionally smaller but quicker and more agile players, of developmental-level rugby teams. Legs were separated into preferred and non-preferred based on kicking preference. Significant difference was not observed but small effect sizes were seen for higher preferred leg peak force values in the forwards (ES = 0.37) and backs (ES = 0.21). The choice to measure effect size instead of significant difference was an attempt to understand the practical significance of the findings as opposed to purely numerical significance[40].

ASYMMETRY IN INDIVIDUALS

A study by Burkett (1970) determined a 10% bilateral difference in hamstring strength would classify an athlete as “high risk” for injury. Out of 31 NFL football players in the study 6 had strength differences of 10% or greater in their hamstrings. Four of those 6 athletes suffered hamstring injuries to the weaker leg and a fifth complained of sever soreness in the weaker leg within three weeks of measurement[41]. A study by Croisier et al. (2008) found athletes with bilateral strength asymmetry of 15% or greater in the hamstrings could significantly reduce injury occurrence if a training program reduced the asymmetry to 5% or less[21]. In regards to performance reduction the previously mentioned study by Mangine et al. (2014) found bilateral asymmetry in the RF and VL negatively affected jumping power and sprint speed of women ($p < 0.05$)[22]. These studies illustrate the importance of understanding and measuring bilateral asymmetry and open the door for future studies to determine better methods for correcting and avoiding asymmetry. Bilateral differences in group data for this study were only as high as 7.0% for PA and FP. However, it is necessary to acknowledge the presence of significant asymmetry between the legs of individual subjects. In this study 8 RT and 7 NRT individuals recorded differences greater than or equal to 10% for FP. Additionally, 18 RT and 8 NRT individuals had greater than or equal to 10% difference in the PA of their VI. Altogether, 31 of the 38 subjects recorded 10% or greater differences between the legs for FP, VI PA, or both. Although these differences between limbs were masked by relative group symmetry, this study indicates a high prevalence of individual asymmetry can be found within a randomly sampled population of males.

RESISTANCE TRAINING

As previously mentioned, group differences as determined by 2-way RM ANOVA analysis were not significant for any factors aside from lean mass and FP in the strong and weak legs. The lack of group differences across all factors except lean mass and FP led to the rejection of the hypothesis that resistance training will affect the level of asymmetry in PA and FP. Because training appeared to have no effect on bilateral asymmetry it is necessary to understand the relationship between training and various muscle parameters. Research by Baroni et al. (2013) displayed the importance of training specificity[36]. The researchers utilized an eccentric training protocol which led to significant increases in muscle fascicle length but not pennation, a typical adaptation seen in other training studies[32,35]. This finding may help explain why no significant difference in PA was seen between the groups in the present study as the type of resistance training performed by the RT group was not recorded.

Prior research from Farup et al. (2012) and Stock et al. (2016) may help explain why differences between the RT and NRT groups were seen for lean mass and FP in the present study[32,35]. Farup et al. (2012) reported 22% and 23% increases in the CSA and PA of the VL as well as a 20% increase in knee extension FP following 10 weeks of resistance training[32]. The differences seen were very similar to the 22%-23% greater lean masses and 28-29% greater knee extension FPs seen in the RT group of the current study. However, the bilateral differences in PA were much lower in the current study, ranging from 8% less in the RT group to 16% greater in the RT group. Stock et al. (2016) examined the effect of 4 weeks of barbell squat and deadlift training on VL strength and architecture. The researchers saw significant increases in leg extension peak torque, MT, and PA[35]. These studies indicate it is possible for muscle architectural and strength parameters to be altered in specific ways (e.g. PA increase, FL increase) by various types of resistance training.

BILATERAL RELATIONSHIP BETWEEN PA AND FP

Previous research has extensively examined the relationship between PA and FP in the legs[15,19,20,26]. However, to our knowledge, no research has examined the symmetry of this relationship between the legs. Gaining an understanding of how PA and FP relate across the legs could be the next step towards using these variables to determine training needs in athletes or to identify deficiencies resulting from prior injury or disease in clinical populations. After collapsing the groups each muscle was examined for a correlation with FP. Only the VI showed statistically significant correlation with FP ($r = 0.242$), therefore the hypothesis that PA and FP would be correlated was only true for the VI. A correlation with VI was expected based on previous research by Ando et al. (2015), who determined the VI architecture had the highest correlation with knee extension force[26]. However, the correlation found by the researchers for MT ($r = 0.74$) and PA ($r = 0.68$) were much higher than the correlation found with PA of the VI in the current study ($r = 0.242$). Additionally, when separated into the stronger and weaker legs or the RT and NRT groups no significant correlation was found for either ($p > 0.05$). The lack of correlation when separated severely limited our ability to analyze the bilateral relationship between the measures. Therefore the hypothesis that the correlation between PA and FP would be consistent between the legs could not be investigated further. It is possible the small sample size and lack of experience of ultrasound measurements by the researchers limited the study's ability to find correlation. This could explain why the VI was not correlated when groups or legs were measured independently and why VM, RF and VL showed no correlation with FP, which was found in previous literature[42]. If possible, future research should examine these factors with a larger group and with a researcher or trained individual who is experienced in the use of ultrasonography.

CHAPTER V

CONCLUSION

The purposes of this study were to: 1) determine the magnitude of asymmetry for PA and FP in the QF 2) determine if a correlation exists between PA and FP 3) determine if the correlation is symmetrical between limbs.

RESEARCH QUESTIONS

1. What is the level of asymmetry for PA in the QF? Group differences in PA ranged from 0.0%-3.4% between the legs. No differences were significant ($p > 0.05$).
2. What is the level of asymmetry for knee extension FP in the QF? This study found a significant difference ($p < 0.001$) with a magnitude of 7.0% between the strong and weak legs. Although this difference was statistically significant it may not be practically significant; differences may not be asymmetrical to the point of decreasing performance or increasing risk for injury.
3. Does a correlation exist between FP and PA in the QF? Correlation was found between the VI and PA ($p = 0.035$, $r = 0.242$), but no correlation was found with any other muscle and PA ($p > 0.05$).
4. What is the effect of resistance training on PA asymmetry? The results of this study indicate individuals who are resistance trained do not exhibit any differences in PA symmetry ($p > 0.05$).
5. What is the effect of resistance training on FP asymmetry? The results of this study indicate individuals who are resistance trained do not exhibit any differences in FP asymmetry ($p > 0.05$).

6. What is the effect of resistance training on the level of correlation between PA and FP in the QF? The results of this study indicate there is no significant effect of training on the correlation between PA and FP in the QF.

CLINICAL SIGNIFICANCE

The absence of architectural asymmetry and the small degree of FP asymmetry suggest that we should expect to see a reasonable degree of symmetry between the limbs for PA and FP. A difference greater than the previously stated 10% could decrease performance or even be indicative of a higher risk for injury. However, because our study only utilized an isometric knee extension, we were unable to measure how asymmetry in some individuals creates performance decrements. The lack of significant changes in symmetry in the RT group indicates resistance training may not be useful for correcting strength imbalances if the training program is not structured specifically with that in mind. However, because the results of this study were weaker than previous studies that have found stronger and more widespread, it is possible a larger study would suggest otherwise.

FUTURE RESEARCH

There are two directions this research should be taken in future studies. The first direction should be to examine these measures on a larger scale in a population who participates in sports where knee injuries are common. Following the measurements, the individuals could be tracked to determine if PA differences, isolated from FP differences, will increase the rate of injury. This population could also be used to examine the effectiveness of specific training designed to reduce asymmetry of both PA and FP on reducing rates of injury. The second direction would be to examine how specific clinical populations with unilateral injuries or strength loss differ from the results seen in the current study's healthy population.

LIMITATIONS

The results of this study are only representative of males age 19-32 years old from the Norman area. Additionally, muscle architecture was estimated based on locations previously determined to be most representative of whole muscle architecture. Two problems were encountered during the data collection process. The first issue occurred when severe weather and/or last minute cancellations by subjects resulted in visits being more than 7 days apart for several subjects. The second issue arose during data analysis as several ultrasound images were not clear enough to determine PA. When this occurred PA of the muscle was estimated by averaging the remaining 2 images. No muscle had less than 2 useable images.

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APPENDIX A

IRB Approval Letter

Informed Consent

Research Privacy Form

Physical Activity Readiness Questionnaire

IPAQ

The UNIVERSITY of OKLAHOMA

Institutional Review Board for the Protection of Human Subjects

Initial Submission – Board Approval

Date: November 20, 2017

To: Rebecca D Larson, PhD

IRB#: 8559
Meeting Date: 11/13/2017
Approval Date: 11/17/2017
Expiration Date: 10/31/2018

Study Title: Bilateral Assessment of Pennation Angle and Force Production in the Quadriceps Femoris

Reference Number: 672228

Study Status: Active - Open

At its regularly scheduled meeting the IRB reviewed the above-referenced research study. Study documents associated with this submission are listed on page 2 of this letter. To review and/or access the submission forms as well as the study documents approved for this submission, open this study from the *My Studies* option, click to open this study, look under Protocol Items to click on the current *Application*, *Informed Consent* and *Other Study Documents*.

If this study required routing through the Office of Research Administration (ORA), you may *not begin your study yet*, as per OUHSC Institutional policy, until the contract through ORA is finalized and signed.

As principal investigator of this research study, it is your responsibility to:

- Conduct the research study in a manner consistent with the requirements of the IRB and federal regulations at 45 CFR 46 and/or 21 CFR 50 and 56.
- Request approval from the IRB prior to implementing any/all modifications.
- Promptly report to the IRB any harm experienced by a participant that is both unanticipated and related per IRB Policy.
- Maintain accurate and complete study records for evaluation by the HRPP quality improvement program and if applicable, inspection by regulatory agencies and/or the study sponsor.
- Promptly submit continuing review documents to the IRB upon notification approximately 60 days prior to the expiration date indicated above.

In addition, it is your responsibility to obtain informed consent and research privacy authorization using the currently approved, stamped forms and retain all original, signed forms, if applicable.

If you have questions about this notification or using iRIS, contact the IRB at 405-271-2045 or irb@ouhsc.edu.

Sincerely,

William R. Leber

William R. Leber, PhD
Vice Chairperson, Institutional Review Board

1105 N. Stonewall Avenue, Oklahoma City, OK 73117 (FWA00007961)

Consent Form
University of Oklahoma Health Sciences Center (OUHSC)
University of Oklahoma-Norman

Bilateral Assessment of Pennation Angle and Force Production in the Quadriceps Femoris

Principal Investigator: Rebecca D. Larson, PhD

This is a research study. Research studies involve only individuals who choose to participate. Please take your time to make your decision. Discuss this with your family and friends.

Why Have I Been Asked To Participate In This Study?
You are being asked to take part in this study because you are between the ages of 18 and 35 and are interested in having your aerobic physical fitness and body composition assessed.

Why Is This Study Being Done?
The purpose of this study is to determine if there are any leg-to-leg differences in the angle of the muscles and how that might be related to leg-to-leg differences in strength.

How Many People Will Take Part In The Study?
About 80 people (40 lower body resistance trained, 40 not lower body resistance trained) will take part in this study.

What Is Involved In The Study?
If you agree to participate, we will ask you to complete 3 study visits where we will use ultrasound to measure the angle of the muscles in both legs and test the strength of your legs. All testing visits will occur in the Body Composition and Human Performance Lab at the University of Oklahoma. The first visit of the study (Visit 1) will be used to measure the angle of your leg muscles on both legs and familiarize you with the process of testing your maximal leg strength. The second visit (Visit 2) will consist of the maximal leg strength test. The third visit (Visit 3) will consist of measuring how much lean and fat tissue your body has and a final test of your leg strength.

Visit #1
On your first visit we will discuss the research study with you and determine your physical readiness to participate in the exercise testing which includes filling out several questionnaires. If you have reasons you should not exercise, you will not be able to participate in the study. We will first ask that you read and sign this informed consent that is approved by the University Institutional Review Board. Also at this time, you will complete a health status questionnaire along with several other questionnaires regarding your physical health. We will then measure your height, weight, resting blood pressure, and resting heart rate. Following that we will use a permanent marker to mark the areas of your lower legs. We will then use ultrasound to measure the angle of your muscles on

both legs. This will be done with an ultrasound apparatus by pressing a probe coated in a water soluble gel against the skin above the muscles being measured. Next you will be fitted and strapped to a specialized piece of equipment that will test your leg strength. You will be placed in this piece of equipment so that your knee and hips are at 90°, similar to that of sitting in a chair with your feet on the ground. You will be asked to perform several attempts at a medium level of effort for each leg so you will become familiarized with the process.

Visit 1 will last approximately 75 minutes.

Visit #2

On your second visit we will once again measure weight, resting blood pressure, and resting heart rate. You will then be fitted to the same piece of equipment as visit 1 that tests your muscle strength using the same settings used during familiarization. The leg strength test protocol will consist of several sub-max or medium effort level attempts at 25%, 50%, and 75% of your maximal effort with 30 seconds of rest between attempts as a warm-up. Following the warm-up you will perform 3 maximal attempts with 2 minutes between attempts. Before each attempt you will be given a countdown then will be encouraged to push as hard as possible for 5 seconds using only the thigh to generate force. Both legs will be tested in randomized order.

Visit 2 will last approximately 30 minutes.

Visit #3

On the third visit we will once again measure weight, resting blood pressure, and resting heart rate. Additionally, we will measure hydration status by having you collect a urine sample in a private restroom. We will use urine specific gravity to determine if you are hydrated. If you are not we will ask you to consume water and return for testing at a later time. You will be asked to undergo a dual X-ray absorptiometry (DXA) scan in order to determine fat mass and lean mass of your legs. This is a non-invasive procedure that requires you to lie down as still and as quietly as possible for approximately 10 minutes. If you participate in this research you will be exposed to radiation from the DXA scans. These scans are for research purposes only, and are not necessary for your medical care. The radiation exposure is less than the daily amount of natural background radiation exposure people in the United States receive. The risk from radiation exposure of this magnitude is too small to be measured directly. The test will be free. Following the DXA scan you will repeat the muscle strength test as you have previously done before.

Visit 3 will last approximately 45 minutes.

How Long Will I Be In The Study?

We think that you will be in the study for 1-2 weeks during which you will visit the Body Composition and Human Performance Lab on 4 occasions. Visits will last between 30 and 75 minutes. We think that the total time you will spend performing testing in the lab will be ~150 minutes.

There may be anticipated circumstances under which your participation may be terminated by the investigator without regard to your consent.

- New information becomes available.
- If it is determined to be in your best medical interest.
- You fail to follow study requirements.

You can stop participating in this study at any time. However, if you decide to stop participating in the study, we encourage you to talk to the researcher and your regular doctor first.

What Are The Risks of The Study?

Radiation Risk from DXA

If you participate in this research, you will be exposed to radiation from a DXA scan (a type of x-ray). The amount of radiation to which you will be exposed from one DXA scan is approximately less than 1% of the amount of radiation that we are exposed to each year from natural background sources of radiation. The risk of radiation exposure is cumulative over your lifetime.

Knee Extension MVC

These tests require that you to exert a maximal effort. The risk for performing these tests is muscle discomfort. You may experience faintness, nausea and/or lightheadedness. You will be closely monitored for any possible ill effects.

Are There Benefits to Taking Part in The Study?

Subjects in both groups will receive personalized information that pertains to their exercise performance and body composition that the subjects can use for their own training.

What Other Options Are There?

You may choose not to participate in the study.

What about Confidentiality?

Efforts will be made to keep your personal information confidential. You will not be identifiable by name or description in any reports or publications about this study. We cannot guarantee absolute confidentiality. Your personal information may be disclosed if required by law. You will be asked to sign a separate authorization form for use or sharing of your protected health information.

There are organizations outside the OUHSC that may inspect and/or copy your research records for quality assurance and data analysis. These organizations include the US Food & Drug Administration and other regulatory agencies. The OUHSC Human Research Participant Program office, the OUHSC Institutional Review Board, and the OUHSC Office of Compliance may also inspect and/or copy your research records for these purposes.

What Are the Costs?
There is no cost to you if you participate in this study.

Will I Be Paid For Participating in This Study?
There is no compensation for participating in this study.

What if I am Injured or Become Ill While Participating in this Study?
In case of injury or illness resulting from this study, emergency medical treatment is available. However, you or your insurance company will be expected to pay the usual charge for this treatment. No funds have been set aside by the University of Oklahoma Health Sciences Center or the University of Oklahoma to compensate you in the event of injury.

What Are My Rights As a Participant?
Taking part in this study is voluntary. You may choose not to participate. Refusal to participate will involve no penalty or loss of benefits to which you are otherwise entitled. If you agree to participate and then decide against it, you can withdraw for any reason and leave the study at any time. You may discontinue your participation at any time without penalty or loss of benefits, to which you are otherwise entitled.

We will provide you with any significant new findings developed during the course of the research that may affect your health, welfare or willingness to continue your participation in this study. You have the right to access the medical information that has been collected about you as a part of this research study. However, you may not have access to this medical information until the entire research study has completely finished. You consent to this temporary restriction.

Whom Do I Call If I have Questions or Problems?
If you have questions, concerns, or complaints about the study or have a research-related injury, contact Dr. Rebecca Larson at 352-359-8432 (cell) or 405-325-6325 (office).

If you cannot reach the Investigator or wish to speak to someone other than the investigator, contact the OUHSC Director, Office of Human Research Participant Protection at 405-271-2045.

For questions about your rights as a research participant, contact the OUHSC Director, Office of Human Research Participant Protection at 405-271-2045.

Signature:
By signing this form, you are agreeing to participate in this research study under the conditions described. You have not given up any of your legal rights or released any individual or entity from liability for negligence. You have been given an opportunity to ask questions. You will be given a copy of this consent document.

I agree to participate in this study:

PARTICIPANT SIGNATURE (age $\geq$18)	Printed Name	Date
SIGNATURE OF PERSON OBTAINING CONSENT	Printed Name	Date

IRB Office Version Date: 09/21/2016

AUTHORIZATION TO USE or SHARE
HEALTH INFORMATION[1] THAT IDENTIFIES YOU FOR RESEARCH
An Informed Consent Document for Research Participation may also be required.
Form 2 must be used for research involving psychotherapy notes.

Title of Research Project: **Bilateral Assessment of Pennation Angle and Force Production in the Quadriceps Femoris**

Leader of Research Team: **Rebecca D Larson, PhD**

Address: **Bilateral Assessment of Pennation Angle and Force Production in the Quadriceps Femoris**

Phone Number: **405-325-6325**

If you decide to sign this document, University of Oklahoma Health Sciences Center (OUHSC) researchers may use or share information that identifies you (protected health information) for their research. Protected health information will be called PHI in this document.

PHI To Be Used or Shared. Federal law requires that researchers get your permission (authorization) to use or share your PHI. If you give permission, the researchers may use or share with the people identified in this Authorization any PHI related to this research from your medical records and from any test results. Information used or shared may include all information relating to any tests, procedures, surveys, or interviews as outlined in the consent form; medical records and charts; name, address, telephone number, date of birth, race, government-issued identification numbers, and can include physical findings from questionnaires, dual X-ray absorptiometry (DXA) scan, and isometric dynamometer tests..

Purposes for Using or Sharing PHI. If you give permission, the researchers may use your PHI to determine if a correlation between force production and pennation angle exists within and between limbs.

Other Use and Sharing of PHI. If you give permission, the researchers may also use your PHI to develop new procedures or commercial products. They may share your PHI with other researchers, the research sponsor and its agents, the OUHSC Institutional Review Board, auditors and inspectors who check the research, and government agencies such as the Food and Drug Administration (FDA) and the Department of Health and Human Services (HHS), and when required by law. The researchers may also share your PHI with no one else.

[1] **Protected Health Information includes all identifiable information relating to any aspect of an individual's health whether past, present or future, created or maintained by a Covered Entity.**

Confidentiality. Although the researchers may report their findings in scientific journals or meetings, they will not identify you in their reports. The researchers will try to keep your information confidential, but confidentiality is not guaranteed. The law does not require everyone receiving the information covered by this document to keep it confidential, so they could release it to others, and federal law may no longer protect it.

YOU UNDERSTAND THAT YOUR PROTECTED HEALTH INFORMATION MAY INCLUDE INFORMATION REGARDING A COMMUNICABLE OR NONCOMMUNICABLE DISEASE.

Voluntary Choice. The choice to give OUHSC researchers permission to use or share your PHI for their research is voluntary. It is completely up to you. No one can force you to give permission. However, you must give permission for OUHSC researchers to use or share your PHI if you want to participate in the research and, if you cancel your authorization, you can no longer participate in this study.

Refusing to give permission will not affect your ability to get routine treatment or health care unrelated to this study from OUHSC.

Canceling Permission. If you give the OUHSC researchers permission to use or share your PHI, you have a right to cancel your permission whenever you want. However, canceling your permission will not apply to information that the researchers have already used, relied on, or shared or to information necessary to maintain the reliability or integrity of this research.

End of Permission. Unless you cancel it, permission for OUHSC researchers to use or share your PHI for their research will never end.

Contacting OUHSC: You may find out if your PHI has been shared, get a copy of your PHI, or cancel your permission at any time by writing to:

Privacy Official University of Oklahoma Health Sciences Center PO Box 26901 Oklahoma City, OK 73190	or	Privacy Board University of Oklahoma Health Sciences Center PO Box 26901 Oklahoma City, OK 73190

If you have questions, call: (405) 271-2511 or (405) 271-2045.

Access to Information. You have the right to access the medical information that has been collected about you as a part of this research study. However, you may not have access to this medical information until the entire research study is completely finished. You consent to this temporary restriction.

Giving Permission. By signing this form, you give OUHSC and OUHSC's researchers led by the Research Team Leader permission to share your PHI for the research project listed at the top of this form.

IRB NUMBER: 8559
IRB APPROVAL DATE: 11/17/2017

Patient/Participant Name (Print): ______________________________

____ ________________
Signature of Patient-Participant Date
or Parent if Participant is a minor

Or

____ ________________
Signature of Legal Representative** Date

**If signed by a Legal Representative of the Patient-Participant, provide a description of the relationship to the Patient-Participant and the authority to act as Legal Representative:

____
OUHSC may ask you to produce evidence of your relationship.

A signed copy of this form must be given to the Patient-Participant or the Legal Representative at the time this signed form is provided to the researcher or his representative.

FORM 3.1 Physical Activity Readiness Questionnaire

Physical Activity Readiness Questionnaire - PAR-Q (revised 2002)

PAR-Q & YOU

(A Questionnaire for People Aged 15 to 69)

Regular physical activity is fun and healthy, and increasingly more people are starting to become more active every day. Being more active is very safe for most people. However, some people should check with their doctor before they start becoming much more physically active.

If you are planning to become much more physically active than you are now, start by answering the seven questions in the box below. If you are between the ages of 15 and 69, the PAR-Q will tell you if you should check with your doctor before you start. If you are over 69 years of age, and you are not used to being very active, check with your doctor.

Common sense is your best guide when you answer these questions. Please read the questions carefully and answer each one honestly: check YES or NO.

YES	NO	
☐	☐	**1. Has your doctor ever said that you have a heart condition and that you should only do physical activity recommended by a doctor?**
☐	☐	**2. Do you feel pain in your chest when you do physical activity?**
☐	☐	**3. In the past month, have you had chest pain when you were not doing physical activity?**
☐	☐	**4. Do you lose your balance because of dizziness or do you ever lose consciousness?**
☐	☐	**5. Do you have a bone or joint problem (for example, back, knee or hip) that could be made worse by a change in your physical activity?**
☐	☐	**6. Is your doctor currently prescribing drugs (for example, water pills) for your blood pressure or heart condition?**
☐	☐	**7. Do you know of any other reason why you should not do physical activity?**

If you answered

YES to one or more questions

Talk with your doctor by phone or in person BEFORE you start becoming much more physically active or BEFORE you have a fitness appraisal. Tell your doctor about the PAR-Q and which questions you answered YES.

- You may be able to do any activity you want — as long as you start slowly and build up gradually. Or, you may need to restrict your activities to those which are safe for you. Talk with your doctor about the kinds of activities you wish to participate in and follow his/her advice.
- Find out which community programs are safe and helpful for you.

NO to all questions

If you answered NO honestly to all PAR-Q questions, you can be reasonably sure that you can:

- start becoming much more physically active – begin slowly and build up gradually. This is the safest and easiest way to go.
- take part in a fitness appraisal – this is an excellent way to determine your basic fitness so that you can plan the best way for you to live actively. It is also highly recommended that you have your blood pressure evaluated. If your reading is over 144/94, talk with your doctor before you start becoming much more physically active.

DELAY BECOMING MUCH MORE ACTIVE:

- if you are not feeling well because of a temporary illness such as a cold or a fever – wait until you feel better; or
- if you are or may be pregnant – talk to your doctor before you start becoming more active.

PLEASE NOTE: If your health changes so that you then answer YES to any of the above questions, tell your fitness or health professional. Ask whether you should change your physical activity plan.

Informed Use of the PAR-Q: The Canadian Society for Exercise Physiology, Health Canada, and their agents assume no liability for persons who undertake physical activity, and if in doubt after completing this questionnaire, consult your doctor prior to physical activity.

No changes permitted. You are encouraged to photocopy the PAR-Q but only if you use the entire form.

NOTE: If the PAR-Q is being given to a person before he or she participates in a physical activity program or a fitness appraisal, this section may be used for legal or administrative purposes.

"I have read, understood and completed this questionnaire. Any questions I had were answered to my full satisfaction."

NAME ____

SIGNATURE ____ DATE ______________________________

SIGNATURE OF PARENT ________________________________ WITNESS ______________________________
or GUARDIAN (for participants under the age of majority)

Note: This physical activity clearance is valid for a maximum of 12 months from the date it is completed and becomes invalid if your condition changes so that you would answer YES to any of the seven questions.

Supported by: Health Canada Santé Canada

continued on other side...

INTERNATIONAL PHYSICAL ACTIVITY QUESTIONNAIRE (October 2002)

LONG LAST 7 DAYS SELF-ADMINISTERED FORMAT

FOR USE WITH YOUNG AND MIDDLE-AGED ADULTS (15-69 years)

The International Physical Activity Questionnaires (IPAQ) comprises a set of 4 questionnaires. Long (5 activity domains asked independently) and short (4 generic items) versions for use by either telephone or self-administered methods are available. The purpose of the questionnaires is to provide common instruments that can be used to obtain internationally comparable data on health–related physical activity.

Background on IPAQ
The development of an international measure for physical activity commenced in Geneva in 1998 and was followed by extensive reliability and validity testing undertaken across 12 countries (14 sites) during 2000. The final results suggest that these measures have acceptable measurement properties for use in many settings and in different languages, and are suitable for national population-based prevalence studies of participation in physical activity.

Using IPAQ
Use of the IPAQ instruments for monitoring and research purposes is encouraged. It is recommended that no changes be made to the order or wording of the questions as this will affect the psychometric properties of the instruments.

Translation from English and Cultural Adaptation
Translation from English is encouraged to facilitate worldwide use of IPAQ. Information on the availability of IPAQ in different languages can be obtained at www.ipaq.ki.se. If a new translation is undertaken we highly recommend using the prescribed back translation methods available on the IPAQ website. If possible please consider making your translated version of IPAQ available to others by contributing it to the IPAQ website. Further details on translation and cultural adaptation can be downloaded from the website.

Further Developments of IPAQ
International collaboration on IPAQ is on-going and an ***International Physical Activity Prevalence Study*** is in progress. For further information see the IPAQ website.

More Information
More detailed information on the IPAQ process and the research methods used in the development of IPAQ instruments is available at www.ipaq.ki.se and Booth, M.L. (2000). *Assessment of Physical Activity: An International Perspective.* Research Quarterly for Exercise and Sport, 71 (2): s114-20. Other scientific publications and presentations on the use of IPAQ are summarized on the website.

INTERNATIONAL PHYSICAL ACTIVITY QUESTIONNAIRE

We are interested in finding out about the kinds of physical activities that people do as part of their everyday lives. The questions will ask you about the time you spent being physically active in the **last 7 days**. Please answer each question even if you do not consider yourself to be an active person. Please think about the activities you do at work, as part of your house and yard work, to get from place to place, and in your spare time for recreation, exercise or sport.

Think about all the **vigorous** and **moderate** activities that you did in the **last 7 days**. **Vigorous** physical activities refer to activities that take hard physical effort and make you breathe much harder than normal. **Moderate** activities refer to activities that take moderate physical effort and make you breathe somewhat harder than normal.

PART 1: JOB-RELATED PHYSICAL ACTIVITY

The first section is about your work. This includes paid jobs, farming, volunteer work, course work, and any other unpaid work that you did outside your home. Do not include unpaid work you might do around your home, like housework, yard work, general maintenance, and caring for your family. These are asked in Part 3.

1. Do you currently have a job or do any unpaid work outside your home?

   ☐ Yes

   ☐ No → ***Skip to PART 2: TRANSPORTATION***

The next questions are about all the physical activity you did in the **last 7 days** as part of your paid or unpaid work. This does not include traveling to and from work.

2. During the **last 7 days**, on how many days did you do **vigorous** physical activities like heavy lifting, digging, heavy construction, or climbing up stairs **as part of your work**? Think about only those physical activities that you did for at least 10 minutes at a time.

   _____ **days per week**

   ☐ No vigorous job-related physical activity → ***Skip to question 4***

3. How much time did you usually spend on one of those days doing **vigorous** physical activities as part of your work?

   _____ **hours per day**
   _____ **minutes per day**

4. Again, think about only those physical activities that you did for at least 10 minutes at a time. During the **last 7 days**, on how many days did you do **moderate** physical activities like carrying light loads **as part of your work**? Please do not include walking.

   _____ **days per week**

   ☐ No moderate job-related physical activity → ***Skip to question 6***

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5. How much time did you usually spend on one of those days doing **moderate** physical activities as part of your work?

_____ **hours per day**
_____ **minutes per day**

6. During the **last 7 days**, on how many days did you **walk** for at least 10 minutes at a time **as part of your work**? Please do not count any walking you did to travel to or from work.

_____ **days per week**

☐ No job-related walking → ***Skip to PART 2: TRANSPORTATION***

7. How much time did you usually spend on one of those days **walking** as part of your work?

_____ **hours per day**
_____ **minutes per day**

PART 2: TRANSPORTATION PHYSICAL ACTIVITY

These questions are about how you traveled from place to place, including to places like work, stores, movies, and so on.

8. During the **last 7 days**, on how many days did you **travel in a motor vehicle** like a train, bus, car, or tram?

_____ **days per week**

☐ No traveling in a motor vehicle → ***Skip to question 10***

9. How much time did you usually spend on one of those days **traveling** in a train, bus, car, tram, or other kind of motor vehicle?

_____ **hours per day**
_____ **minutes per day**

Now think only about the **bicycling** and **walking** you might have done to travel to and from work, to do errands, or to go from place to place.

10. During the **last 7 days**, on how many days did you **bicycle** for at least 10 minutes at a time to go **from place to place**?

_____ **days per week**

☐ No bicycling from place to place → ***Skip to question 12***

11. How much time did you usually spend on one of those days to **bicycle** from place to place?

_____ **hours per day**
_____ **minutes per day**

12. During the **last 7 days**, on how many days did you **walk** for at least 10 minutes at a time to go **from place to place**?

_____ **days per week**

☐ No walking from place to place → ***Skip to PART 3: HOUSEWORK, HOUSE MAINTENANCE, AND CARING FOR FAMILY***

13. How much time did you usually spend on one of those days **walking** from place to place?

_____ **hours per day**
_____ **minutes per day**

PART 3: HOUSEWORK, HOUSE MAINTENANCE, AND CARING FOR FAMILY

This section is about some of the physical activities you might have done in the **last 7 days** in and around your home, like housework, gardening, yard work, general maintenance work, and caring for your family.

14. Think about only those physical activities that you did for at least 10 minutes at a time. During the **last 7 days**, on how many days did you do **vigorous** physical activities like heavy lifting, chopping wood, shoveling snow, or digging **in the garden or yard**?

_____ **days per week**

☐ No vigorous activity in garden or yard → ***Skip to question 16***

15. How much time did you usually spend on one of those days doing **vigorous** physical activities in the garden or yard?

_____ **hours per day**
_____ **minutes per day**

16. Again, think about only those physical activities that you did for at least 10 minutes at a time. During the **last 7 days**, on how many days did you do **moderate** activities like carrying light loads, sweeping, washing windows, and raking **in the garden or yard**?

_____ **days per week**

☐ No moderate activity in garden or yard → ***Skip to question 18***

17. How much time did you usually spend on one of those days doing **moderate** physical activities in the garden or yard?

_____ **hours per day**
_____ **minutes per day**

18. Once again, think about only those physical activities that you did for at least 10 minutes at a time. During the **last 7 days**, on how many days did you do **moderate** activities like carrying light loads, washing windows, scrubbing floors and sweeping **inside your home**?

_____ **days per week**

☐ No moderate activity inside home → ***Skip to PART 4: RECREATION, SPORT AND LEISURE-TIME PHYSICAL ACTIVITY***

19. How much time did you usually spend on one of those days doing **moderate** physical activities inside your home?

_____ **hours per day**
_____ **minutes per day**

PART 4: RECREATION, SPORT, AND LEISURE-TIME PHYSICAL ACTIVITY

This section is about all the physical activities that you did in the **last 7 days** solely for recreation, sport, exercise or leisure. Please do not include any activities you have already mentioned.

20. Not counting any walking you have already mentioned, during the **last 7 days**, on how many days did you **walk** for at least 10 minutes at a time **in your leisure time**?

_____ **days per week**

☐ No walking in leisure time → ***Skip to question 22***

21. How much time did you usually spend on one of those days **walking** in your leisure time?

_____ **hours per day**
_____ **minutes per day**

22. Think about only those physical activities that you did for at least 10 minutes at a time. During the **last 7 days**, on how many days did you do **vigorous** physical activities like aerobics, running, fast bicycling, or fast swimming **in your leisure time**?

_____ **days per week**

☐ No vigorous activity in leisure time → ***Skip to question 24***

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23. How much time did you usually spend on one of those days doing **vigorous** physical activities in your leisure time?

_____ **hours per day**
_____ **minutes per day**

24. Again, think about only those physical activities that you did for at least 10 minutes at a time. During the **last 7 days**, on how many days did you do **moderate** physical activities like bicycling at a regular pace, swimming at a regular pace, and doubles tennis **in your leisure time**?

_____ **days per week**

☐ No moderate activity in leisure time → ***Skip to PART 5: TIME SPENT SITTING***

25. How much time did you usually spend on one of those days doing **moderate** physical activities in your leisure time?
_____ **hours per day**
_____ **minutes per day**

PART 5: TIME SPENT SITTING

The last questions are about the time you spend sitting while at work, at home, while doing course work and during leisure time. This may include time spent sitting at a desk, visiting friends, reading or sitting or lying down to watch television. Do not include any time spent sitting in a motor vehicle that you have already told me about.

26. During the **last 7 days**, how much time did you usually spend **sitting** on a **weekday**?

_____ **hours per day**
_____ **minutes per day**

27. During the **last 7 days**, how much time did you usually spend **sitting** on a **weekend day**?

_____ **hours per day**
_____ **minutes per day**

This is the end of the questionnaire, thank you for participating.

APPENDIX B

KinCom/Subject Measures Data Sheet

Pennation Measurement Data Sheet

Researcher(s): ____ Visit: 1 2 3

Subject ID: ___________ Date: ______________ Time: ______________

Age: ___________ Height (cm): ___________ Weight (kg): ___________

Urine Specific Gravity: ______________ Resting Blood Pressure: __________ ___________

Limb Length (cm): ______________ Dominant Limb: L R

Right Leg: _____ 22%: _____ 56%: _____ Left Leg: _____ 22%: _____ 56%: _____

Pennation Angle

Right leg:

VM: ____________ VL: _____________ RF: _____________ VI: _____________

Left Leg:

VM: ____________ VL: _____________ RF: _____________ VI: _____________

Kin Com Settings:

Lever Arm: _____________ Seat: ______________ Dynamometer: _____________

Height: _____________

First Leg: ___________

Trial 1: ___________ Trial 2: ____________ Trial 3: ____________ Average: ____________

Second leg: _____________

Trial 1: ___________ Trial 2: ____________ Trial 3: _____________ Average: ____________

Researcher: _____

Subject: ____________

RVM 1: ___ ___ ___ avg ___	
RVM 2: ___ ___ ___ avg ___	RVM avg: ___
RVM 3: ___ ___ ___ avg ___	
RVL 1: ___ ___ ___ avg ___	
RVL 2: ___ ___ ___ avg ___	RVL avg:___
RVL 3: ___ ___ ___ avg ___	
RRF 1: ___ ___ ___ avg ___	
RRF 2: ___ ___ ___ avg ___	RRF avg:___
RRF 3: ___ ___ ___ avg ___	
RVI 1: ___ ___ ___ avg ___	
RVI 2: ___ ___ ___ avg ___	RVI avg:___
RVI 3: ___ ___ ___ avg ___	
LVM 1: ___ ___ ___ avg ___	
LVM 2: ___ ___ ___ avg ___	LVM avg:___
LVM 3: ___ ___ ___ avg ___	
LVL 1: ___ ___ ___ avg ___	
LVL 2: ___ ___ ___ avg ___	LVL avg:___
LVL 3: ___ ___ ___ avg ___	
LRF 1: ___ ___ ___ avg ___	
LRF 2: ___ ___ ___ avg ___	LRF avg:___
LRF 3: ___ ___ ___ avg ___	
LVI 1: ___ ___ ___ avg ___	
LVI 2: ___ ___ ___ avg ___	LVI avg:___
LVI 3: ___ ___ ___ avg ___	